Learning Analytics for a Puzzle Game to Discover the Puzzle-Solving Tactics of Players

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Abstract. Games can be used as effective learning tools, proved to enhance players' performance in a wide variety of cognitive tasks. In this context, Learning Analytics (LA) can be used to improve game quality and to support the achievement of learning goals. In this paper, we investigate the use of LA in digital puzzle games, which are commonly used for educational purposes. We describe our approach to explore the way players learn game skills and solve problems in an open-source puzzle game called *Lix*. We performed an initial study with 15 participants, in which we applied Process Mining and cluster analysis in a three-step analysis approach. This approach can be used as a basis for recommending interventions so as to facilitate the puzzle-solving process of players.

Keywords: Learning Analytics · Educational Data Mining · Serious games · Puzzle games · Technology enhanced learning · Cluster analysis · Process mining

1 Introduction

There is a growing field of investigation on the application of games as technology-enhanced learning tools, used to complement or enhance traditional education [1]. Learning Analytics (LA) and Educational Data Mining (EDM) can be applied in combination with game analytics to improve game quality and to support the achievement of learning goals [2,3]. Various methods of analytics in e-learning and game analytics help researchers make sense of data collected from user behavior, particularly through the use of modeling techniques [4] such as Process Mining (PM) [5,6] and cluster analysis [7].

In this paper, we propose the use of LA methods in one specific class of games: digital puzzle games. This type of game is commonly used for educational purposes [8], possibly given its typical reliance on problem-solving and on logical and mathematical intelligence [9]. We describe our approach to explore

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the way players learn game skills and solve problems in the game, automatically extracting players' tactics and creating reference models for further analysis of other players' behavior.

We developed and tested our proposed approach in a puzzle game that offered an adequate development and testing environment, given its constrained interaction, deterministic game engine, clear success criteria, and limited dependence on external knowledge. Our goal is to define an analytics approach that can be extended to different types of learning games. Additionally, we aim to use this approach in the future to support the implementation of automatic adaptive features for educational games, such as targeted interventions, appropriate feedback, and timely hints for the player/learner.

2 Game Description and Data Collection

We extended an existing open-source puzzle game called *Lix* [10], which is inspired by *Lemmings*, a 1991 game by DMA Design. In *Lix*, the objective is to guide a group of simple characters to a designated exit (Fig. 1).

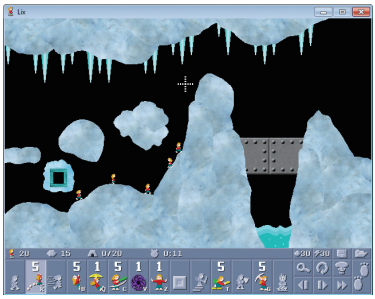

Fig. 1. *Lix* game interface.

To collect game data, we altered the game following a Service-Oriented Architecture approach [11]. The game performs network calls to a web service that listens to relevant game events, and records them in a database. The events recorded are of two types: *game* traces and *meaningful variable* traces [3]. The *game* traces indicate timestamps of when the player started the game, started or restarted a puzzle, paused the game and returned to the menu. The *meaningful variable* traces consist of a simple record of a timestamp, a short code describing the skill assigned to a character, an internal identifier of the character to which the skill was assigned and an internal measure of game time.

We collected preliminary game data in a study with 15 adult participants. Participants were given a brief explanation of the study and of the goal of the game. No explanations about the game user interface were given. Participants were given a pre-test questionnaire to collect demographic data and gaming

experience. They were asked to play one intermediate level puzzle of the game as many times as they wanted. They were asked to think aloud for us to take notes on their reactions, tactics, persistence, etc. The data was used to develop our analytics approach, explained in the next section.

3 Analytics Approach

We developed a data-driven analytics approach that combines PM and cluster analysis to discover the way players learn skills, solve problems, and succeed in a specific puzzle game. In particular, our objective was to discover the clusters of the tactics applied by the players and identify a reference sequence for each cluster. We obtained the reference sequences by building the process models of tactics. These process models identify the most significant activities and transitions through PM. The reference sequences play a central role in validation of the results. By comparing a player's process to previously established successful references, we aim to detect whether the player behaves closely to them.

Our analytics approach comprises of three main steps. A preliminary step is collecting the data from the game ('A' in Fig. 2), as explained in Sect. 2. The first step is to identify the tactics adopted in the game by players through cluster analysis ('B'). In the second step, we aim to obtain the process models of the identified tactics through PM. These models represent the most significant components of the tactics which yield references that are central in validation of our results ('C'). Finally, we validate the results of cluster analysis and PM by measuring how the elements of a tactic cluster converge to their reference ('D').

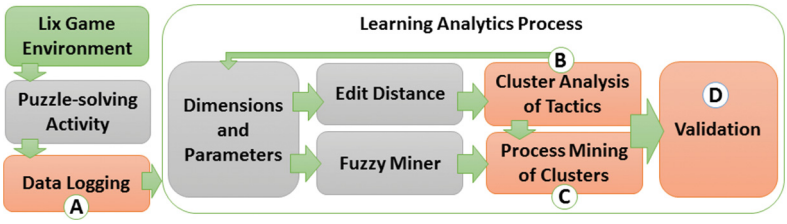

Fig. 2. Learning Analytics approach

4 Conclusions

In this study, we present a novel approach to apply LA methods on interaction data collected from an open-source puzzle game called *Lix*. This game is used in our study because of the value of puzzle games for educational purposes [8,9], and, as such, developing ways to automatically analyze players' problem-solving processes can be a valuable tool for educators and game designers alike.

We presented a three-step analytics approach that uses clustering, process mining, and validation to extract the puzzle-solving tactics from data, even without previous knowledge about the nature of the puzzle. The advantages of this approach can be explained as follows: we can identify previously unknown tactics, and not only the ones assumed by the game designer. We can avoid manually defining optimal strategies for every level of a game. Also, this approach can raise awareness of the educators about the learning progress by visualizing how close or far away from the optimal tactic any player is.

The results confirms that our LA approach was successful: two main successful tactics were discovered through cluster analysis, the process models of these tactics were successfully obtained, and yielded references for validation. Finally, the validation results indicate that we obtained meaningful clusters of different tactics, as the members of each cluster converged to their reference.

In the future, we will verify our approach by reporting the results and applying the same methodology to more data, in order to cross-validate the obtained process models. Additionally, we aim to extend our approach to other skill-based puzzle games, using it as input to automatically recognize the different stages of puzzle solving and to detect which players are most likely to quit the game. Finally, we plan to use this approach as the basis for recommending interventions that could allow the game to provide the player/learner with help on time, for instance by automatically comparing a given player's tactic to the successful tactics identified by this approach.

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Preface

The 11th edition of the European Conference on Technology-Enhanced Learning (EC-TEL) was held in Lyon (France) during September 13–16, 2016. This volume collects all peer-reviewed contributions that were included in the exciting program of this year's conference.

In the 11th year of its existence, EC-TEL has become the major interdisciplinary venue for the community of technology-enhanced learning (TEL) researchers in Europe and worldwide. Furthermore, EC-TEL is a shared opportunity for researchers, practitioners, educational developers, and policy makers to address current challenges and advances in the field. Since 2006, EC-TEL has provided a reference point for relevant state-of-the art research in TEL; first in Crete (Greece, also in 2007), and then in Maastricht (The Netherlands, 2008), Nice (France, 2009), Barcelona (Spain, 2010), Palermo (Italy, 2011), Saarbrücken (Germany, 2012), Paphos (Cyprus, 2013), Graz (Austria, 2014), and Toledo (Spain, 2015).

In these uncertain and turbulent times, it is essential for individuals and organizations continually to adapt and change. The theme of EC-TEL 2016 was "Adaptive and Adaptable Learning." It highlighted developments in learning systems that adapt to the needs, interests, and abilities of each learner, toward a vision of learning that is personalized yet social. Effective technology enhanced learning must also be adaptable – resilient, flexible, and sustainable to meet rapidly changing needs, technologies, contexts, and policies. The conference explored how research in collaborative and personalized learning could be combined with new developments in analytics, interaction design, social, mobile and ubiquitous technologies, and visualization techniques, to enhance learning for everyone.

Drawing on the core TEL disciplines of computer science, education, psychology, cognitive science, and social science, research contributions presented at EC-TEL 2016 addressed topics such as adaptive and adaptable learning, collaborative knowledge building, motivation and engagement, collaborative learning, game-based learning, lifelong learning, intelligent learning systems, recommender systems, learning design, learning analytics, assessment for learning, social computing and social media, massive open online courses (MOOCs), and wearable and pervasive technologies.

This 2016 edition was again extremely competitive, given the high number of submissions generated. A total of 148 valid paper submissions were received. Of these, 102 were full papers. All submissions were assigned to at least three members of the Program Committee (PC) for review. One of the reviewers had the role of leading reviewer and initiated a discussion in the case of conflicting reviews. All reviews as well as the discussions were checked and discussed within the team of PC chairs, and additional reviews or meta-reviews were elicited if necessary. From this process, 26 submissions were selected as full papers (resulting in an acceptance rate for full papers of 25 %). Additionally, 23 papers were chosen as short papers, eight as demonstrations, and 33 as posters. Table 1 shows the detailed statistics.

Table 1. Acceptance rate in different submission categories

		Published as			
Submitted as		Full Paper	Short Paper	Poster Paper	Demo Paper
Full Paper	102	26	16	21	2
Short Paper	31		7	8	
Poster Paper	9			4	
Demo Paper	6				6
Sum	148	26	23	33	8

The dedicated work of all the PC members as well as the additional reviewers must be acknowledged. Only with their help was it possible to deal with the high number of submissions and still meet all deadlines as originally planned.

Keynote presentations completed this competitive scientific program. Pierre Dillenbourg from the EPFL Center for Digital Education, Switzerland, gave a presentation on "How Does TEL Research Inform the Design of Educational Robots?" and Vincent Aleven from Carnegie Mellon University presented on "Adaptivity in Learning Technologies: Kinds, Effectiveness, and Authoring." A keynote from the European Commission covered policy aspects of technology enhanced learning.

A plenary panel session was held on the theme of the conference – Adaptive and Adaptable Learning. Two invited panelists from the artificial intelligence and education community, Benedict du Boulay and Rose Luckin, joined the researchers from the TEL community.

Demonstrations and posters had a pronounced role in the conference program. A plenary session was organized as a "TEL demo shootout" in which the demonstrations were presented to arouse the audience's curiosity and highlight the unique aspects. Later on, the demonstrations were shown in action, giving participants the opportunity for hands-on experience, sparking discussions between researchers, practitioners, and educational developers, providing a basis to vote for the best demo. A plenary session was dedicated to an exhibition of posters, to foster discussion about work in progress and research issues. Representatives from the industry also presented and discussed their contributions to the field in the industry track.

The TEL community proposed and organized a set of stimulating workshops as part of the conference. In all, nine workshops were selected from the proposals and were organized. Some of them continue a series of well-established workshops on motivational and affective aspects in TEL and on awareness and reflection in TEL. Others, like Pedagogical Grounded Learning Analytics Design, were new for 2016. A doctoral consortium was organized concurrently with the workshops, which provided an opportunity for PhD students to discuss their work with experienced TEL researchers.

We would like to thank the many contributors for creating a stimulating conference of high quality. These include foremost the authors, the PC members and reviewers, and the conference chairs, who all contributed to the program. We would also like to thank an enthusiastic and dedicated local organization team who made EC-TEL

a smooth and memorable experience. The conference was partially supported by the European Association of Technology-Enhanced Learning (EATEL), Springer, and EasyChair.

September 2016

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